PHY132 Practicals Day 2
Student Guide

Summer 2009

Concepts of today's Module

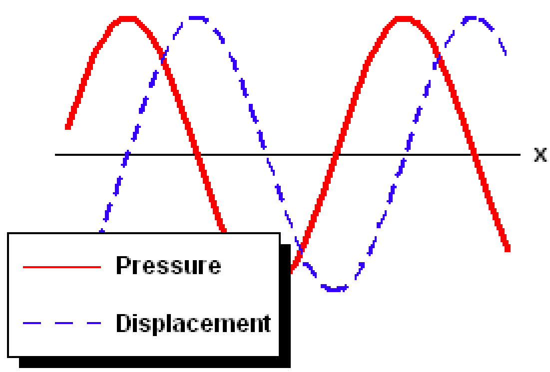
- Superposition
- Standing Waves

Waves Module 1, Activity 8

As investigated in Waves Module 1, Activity 4 (done last day), we can think of a sound wave two different ways:

1. A pressure wave. The pressure oscillates around atmospheric pressure.
2. A displacement wave. The displacements of the air molecules oscillate around their equilibrium positions.

These two waves are 90 degrees out of phase: when one has a maximum or minimum the other is at zero amplitude.

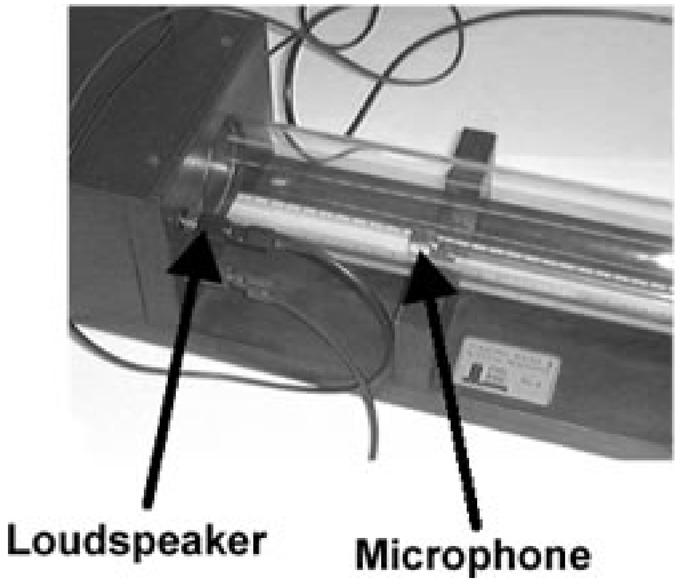


You will want to know that microphones measure the *pressure* wave. You will also want to know that the speed of sound is:

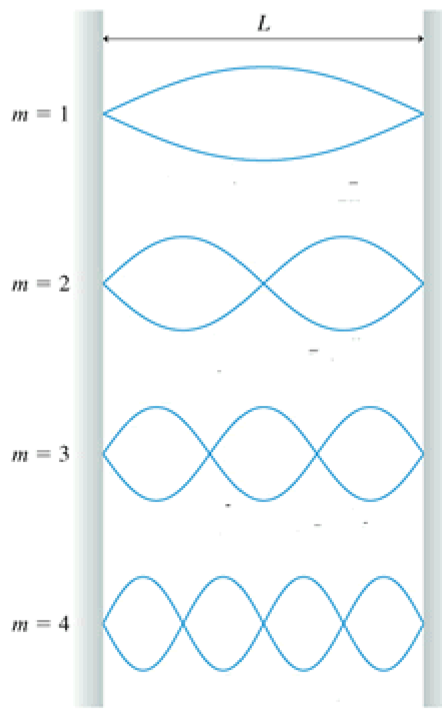
$$v_{accepted} = 331 + 0.61T \ \text{(m/s)}$$

where T is the temperature of the air in Celsius.

In this Activity you will set up standing sound waves in a tube filled with air. A loudspeaker generates the sound wave. A rod inside the tube has a small microphone mounted on the end, so the sound wave inside the tube can be measured at different positions. The part of the tube with the loudspeaker is shown in the figure on the next page.



When the tube is closed at both ends, the possible *displacement* standing waves are the same as those for a standing waves on a string that is fixed at both ends: there is a node at each end of the tube. The figure to the right shows the first four possible standing waves. These are the same standing waves that for a string we called *normal modes* in Activity 7, and in fact this is the same figure that appears there!



A. What are the wavelengths of the shown standing waves? What is the wavelength of the $m = 5$ standing wave which is not shown? Generalise to a formula for the wavelengths for any value of m.
B. For the first two or three displacement standing waves, sketch the corresponding *pressure* standing wave.

Here is a link to a simple Flash animation that shows the displacement wave for the first three standing waves:

http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/Flash/sta2fix.html

Be careful not to push the Sound Sensor all the way into the speaker, as the speaker is made of paper!

Set up the tube on the table with the speaker further away from the computer.
The Data Acquisition Device (DAQ) is designed to interface between the computer and physical apparatus. It has two purposes for this experiment:

1. The DAQ generates a variable voltage which drives the magnet in the speaker and creates a sound. This is the ***input*** signal for the sound-tube.
2. The DAQ amplifies and measures the small variable voltage generated by the Sound Sensor, or microphone. This is the ***output*** signal from the sound-tube, which you will be measuring.

Plug the wire from the Sound Sensor into the **A (ai2) Analog Sensor** plug in the DAQ.

Plug the wire from the Speaker into the **ao0 Analog Output** plug in the DAQ. This connector is called a BNC and must be pushed in and twisted clockwise a ¼ turn until it ‘clicks’.

On the computer, open the Labview program which generates the output signal to the speaker and also measures and displays the input from the Sound Sensor. This program is at: My Computer → public on 'feynman' (P:) → Modules →Waves→ Speed of Sound Tube
Notes:

- You have to ‘Run’ the program to get anything to happen (the button with the small white arrow)
- To start the speaker, first click ‘Acquire Data’ so it turns green, then click on ‘Function Generator’ so it turns green
- To turn off the speaker click ‘Acquire Data’ again so it turns off. At this point you can use the cursors to measure the amplitude and period of the wave.

Testing the signal input

C. Make a sound by clicking on the Function Generator button. Adjust the frequency through the range from the minimum frequency to the maxiximum in intervals of about 500 Hz. Record your observations, including what you hear. For one frequency, try the different signal types, and record your observations, including what you hear. For the remainder of this activity, you will be using the Sine Wave.

Testing the Sound Sensor output

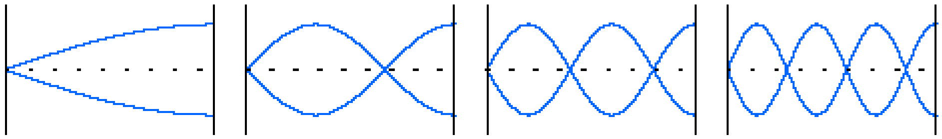
D. The graph which is displayed shows the pressure wave as measured by the sound sensor. Remove the Sound Sensor from the tube, keeping it attached to the meter stick. Turn off the Function Generator and try talking (or whistling!) into the sensor. (Please do not shout!!). Record your observations.

Getting a Standing Wave in the Tube

Have the tube closed at both ends. For some frequency between, say, 200 Hz and 2 kHz, adjust the frequency so that a standing wave exists in the tube. One way to adjust the frequency for a good standing wave is to place the microphone as close to the loudspeaker as possible. Now adjust so that the amplitude as measured by the microphone is a maximum; recall that this corresponds to the displacement of the air molecules from their equilibrium position being a minimum. A secondary adjustment can be made by placing the microphone at the position of a node in the pressure wave and making small adjustments of the frequency to make the measured amplitude as small as possible.

E. How much can you vary the frequency of the wave and not observe any difference in whether or not there is a good standing wave in the tube?
F. Put your ear close to the tube and note how loud the sound is. Adjust the frequency so that there is no longer a standing wave in the tube. How does the sound level compare to when there is a standing wave? Explain.
G. Get a good standing wave in the tube. Probe the standing wave with the microphone to determine the wavelength of the standing wave. What is your uncertainty in this determination? As you will discover in Part G, you should not just determine the wavelength from the number of nodes and the length of the tube. From your measurements of the frequency and wavelength calculate the speed of sound and its uncertainty. How does your value compare with the accepted value given above?
H. Repeat Parts E – G for a few more frequencies.
I. For the lowest frequencies, the maximum amplitude as measured by the microphone does not occur at the position of the loudspeaker, but a noticeable and measurable distance down the tube away from it. This is your first indication that the simple picture of these waves as described above is not quite complete. Choose one of the low frequency standing waves that you have discovered, and determine the value of this distance.

When one end of the tube is open to the air, the standing waves that are possible are the same as those for a vibrating string with one loose end. Here are some of these standing waves:



These standing waves occur because part of the incident sound wave is reflected from the open end of the tube. However, the effective reflection point of the wave is not the exact position of the open end of the tube but is slightly beyond it, and so the effective length of the tube is greater than its real length:

$$L_{effective} = L_{real} + \Delta L$$

where:

$$\Delta L \approx 0.3D$$

and D is the diameter of the tube. Sometimes $L_{effective}$ is called the *acoustic length*.

Here is a link to a simple animation that shows the first three standing waves:

http://faraday.physics.utoronto.ca/IYearLab/Intros/StandingWaves/Flash/sta1fix.html

J. Set up one or more standing waves in the tube with one end open and determine the effective length of the tube. How well do you measurements agree with the value given above?
K. If someone designs a pipe organ without being aware of the acoustic length, what will be the consequences?

If you have time: Activity 9

[***STOP!*** Please go back and take a second look at what you have recorded in your notebook for the mandatory activities. Is there anything missing? Can anything be improved? Does your TA have advice on what you might be able to do better? Please do not attempt this "If you have time" activity until you feel confident that the other activities are completed to the best of your ability, and you have obtained permission from one of your TAs.]

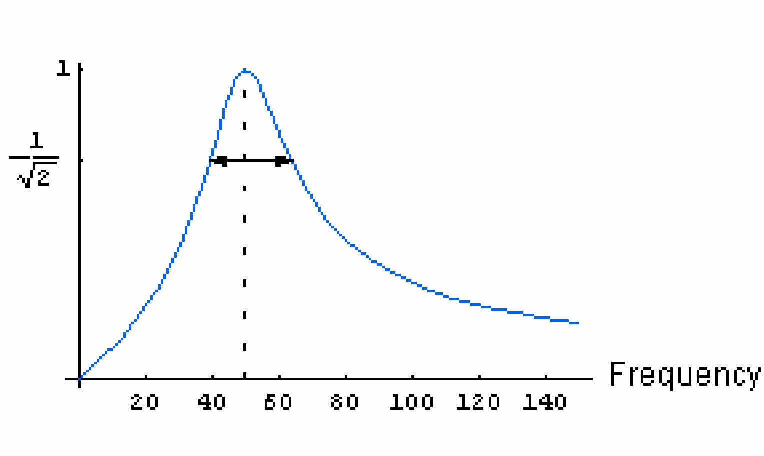
If the apparatus of Waves Module 1, Activity 8 were perfect, then when the tube is closed on both ends we would not hear any sound outside the tube. Similarly, if the air inside the tube were perfect, all molecule-molecule collisions would be perfectly elastic; this means that as a sound wave travels through the air none of its energy would be converted to heat energy of the air. However, neither the apparatus nor the air is perfect, The *Quality Factor Q* measures the degree of "perfection" of the system.

Say we have a standing wave when the frequency is f_0. For frequencies close to the "resonant frequency" f_0 the amplitude A of the sound wave at the position where there was an maximum in the pressure wave is given by:

$$A(f) = A_o \frac{1}{\sqrt{1 + Q^2\left(\frac{f}{f_o} - \frac{f_o}{f}\right)^2}}$$

Note in the above that the amplitude $A(f)$ is equal to A_0 when the frequency f is equal to the resonant freqency .

The figure to the right shows $A(f)$ for A_0 equal to 1, Q equal 2, and for a resonant frequency of 50 Hz. Note that we have indicated the width of the curve where the maximum amplitude is $1/\sqrt{2}$ times the maximum amplitude A_0.



A nearly trivial amount of algebra shows that the amplitude A is $1/\sqrt{2}$ times the maximum amplitude A_0 for positive frequencies when the frequency is:

$$f = \frac{f_0}{2Q}(\sqrt{1+4Q^2} \pm 1)$$

Thus, if the width of the curve is Δf, then Q is:

$$Q = \frac{f_0}{\Delta f}$$

A. For a given resonant frequency f_0 how does the width of the curve of amplitude versus frequency depend on the Quality Factor Q?
B. When the Quality Factor Q is zero, the maximum amplitude A_0 is zero. When Q is infinite so is the maximum amplitude. Explain.
C. Close the tube at both ends and adjust for a standing wave in the range of 200 Hz - 1 kHz. Place the microphone at a maximum in the pressure wave and take data for the amplitude as a function of frequency for frequencies close to the resonant frequency. Calculate the Quality Factor of the tube.

Last revision to this write-up: July 5, 2009 by Jason Harlow.

This Waves Module 1 Student Guide was written by David M. Harrison, Dept. of Physics, Univ. of Toronto in the Fall of 2008. The figure of normal modes of a vibrating string in Activity 7 is slightly modified from Figure 21.22 of Randall D. Knight, **Physics for Scientists and Engineers,** 2nd edition (Pearson Addison-Wesley, 2008), pg. 640. The same figure is used in Activity 8. Activities 8 and 9 are based on a Student Guide written by David M. Harrison in October 1999 and revised in June 2001.